0.001), and medial meniscus (ρ = 0.34, P= 0.020) scores in the OA group. The difference in mechanical axis between the 3 groups was not significant.

**Table 1**
Results from the generalized estimating equations for associations of knee flexion and adduction impulses with the MR parameters in the three groups

| | | Young | | | Middle-aged non-OA | | | OA | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Coefficient | 95 % CI | P | Coefficient | 95 % CI | P | Coefficient | 95 % CI | P |
| **Knee flexion impulse** | | | | | | | | | | |
| **Tibiofemoral** | $T_{1p}$ | -486.4 | -653.7,-319.0 | **<0.001** | 253.3 | -35.8, 542.5 | 0.086 | 128.5 | 42.7, 214.3 | **0.003** |
| | $T_2$ | -377.7 | -242.6, -512.9 | **<0.001** | 301.9 | 85.2, 518.5 | **0.006** | 199.4 | 55.8, 343.1 | **0.006** |
| **Global Meniscus** | $T_{1p}$ | -222.**1** | -80.3, -363.9 | **0.002** | 25.6 | -130.1, 181.2 | 0.748 | 32.2 | -129.0, 193.4 | 0.696 |
| | $T_2$ | -198.3 | -52.7, -344.0 | **0.008** | 28.7 | -115.7, 173.1 | 0.697 | 81.8 | -142.5, 306.1 | 0.475 |
| **Knee adduction impulse** | | | | | | | | | | |
| **Medial Cartilage** | $T_{1p}$ | 89.4 | -194.8, 373.7 | 0.537 | 76.4 | -371.0, 523.8 | 0.738 | 284.0 | -210.7, 778.8 | 0.261 |
| | $T_2$ | -164 | -249.6, 216.7 | 0.890 | 167.7 | -160.1, 495.6 | 0.316 | 336.6 | 87.0, 586.2 | **0.008** |
| **Medial Meniscus** | $T_{1p}$ | 290.2 | 22.9, 557.6 | **0.033** | -22.8 | -200.87, 155.2 | 0.802 | 285.6 | 52.8, 518.3 | **0.016** |
| | $T_2$ | 224.2 | -42.7, 491.1 | 0.100 | -57.6 | -233.9, 118.7 | 0.522 | 478.5 | 224.5, 732.6 | **<0.001** |

**Conclusions**: Higher sagittal loads were related to lower cartilage T1ρ and T2 in young subjects suggesting higher proteoglyan (PG) and collagen concentration. This association reverses partially in the middle-aged group and completely in the OA group. Osteoarthritic cartilage may not be able to respond positively to physiological loading leading to vicious cycle of further degeneration. Meniscus also showed similar pattern where higher sagittal loads were related to better composition in young subjects but this association was not present in the OA group. Frontal plane loads on the other hand showed negative association with meniscus cartilage composition across all groups with stronger associations in the OA group. Hence, frontal plane loading may impact knee OA onset through its association with meniscus rather than articular cartilage. Once OA has developed, greater adduction impulse and greater varus were both related to worse medial cartilage morphology and composition. The findings highlight the importance of sagittal loads, in addition to, frontal loads, towards cartilage degeneration in people with knee OA. This study was funded by NIH-NIAMS RO1 AR046905 and R01 AR062370.

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## THE EFFECT OF QUADRICEPS-STRENGTHENING EXERCISE ON QUADRICEPS AND KNEE BIOMICHANICS DURING WALKING IN ADULTS WITH KNEE OSTEOARTHRITIS: A RANDOMIZED CONTROLLED TRIAL

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**Purpose**: In people with tibio-femoral osteoarthritis (OA) pain and reduced muscle strength are the primary reasons for disability and lower quality of life. Quadriceps strengthening reduces pain and improves physical function and is thought to be protective of the knee from aberrant loadings. The underlying theory dictates that quadriceps strength training will increase quadriceps force and negative work and thereby unload the tibio-femoral joint during walking. This biomechanical mechanism is theoretically flawed however in that larger quadriceps force will directly increase tibio-femoral joint load, and negative muscle work does not reduce joint loads but total body mechanical energy. Certainly muscle strength and muscle function are pivotal for knee OA patients in terms of general physical function, but the alleged biomechanical mechanism of quadriceps strengthening have not been supported with empirical data. The aim of the study is to evaluate the effect of quadriceps strengthening on the quadriceps muscle force production and tibio-femoral joint loading during walking in adults with knee OA.

**Methods**: This study is a two-center randomized controlled trial including adults with tibio-femoral OA (ClinicalTrials.gov/NCT01538407). Participants were randomly allocated to a 12 weeks of quadriceps strengthening group or a control group (no attention). All participants had 3D gait analyses, muscle strength, and WOMAC data collected before and after the 12-week period. Quadriceps strengthening consisted of facility based sessions (3 times/week) including leg extension, leg press and lunge exercises performed in 3 sets of 10 repetitions with loads increasing from 65% to 80% of 3RM. Change from baseline in peak quadriceps force during walking at 12 weeks was the registered primary outcome. The first peak quadriceps muscle force and peak knee compressive force during level walking at self-selected speed were quantified using kinematic and kinetic data in combination with a biomechanical knee model previously published (Figure 1). Two-way ANCOVAs adjusted for age, gender, baseline value, and study center were performed to investigate the effects of strengthening exercises on changes in knee loadings and quadriceps force.

**Results**: Thirty-one adults with knee OA volunteered for the study, but one was excluded at screening due to knee joint effusion. In total we included 30 participants, 18 females and 12 males with a mean age of 57.1 ± SD 7.7 years and BMI 27.1 ± SD 4.0 kg/m2. Following the randomization groups were very similar and differed by less than 4%, on average, in age, height and BMI. Participants in the strength training group completed at least 30 sessions (80%) of the possible 36 training sessions. The training group exhibited a significantly higher increase in isometric quadriceps strength as well as lower scores (i.e. improvement) in pain, function, and total WOMAC compared to the control group (all p<0.05). There were no group differences in the changes in quadriceps or knee compressive forces (Table 1).

**Conclusions**: Despite improvements in strength, pain, and function, quadriceps-strengthening exercise did not change quadriceps force or knee loadings during level walking in adults with knee OA. The findings of this study suggest that pain relief and improvements in function are not followed by changes in knee joint biomechanics, such as quadriceps force and knee joint loadings. Moreover, increased muscle strength does not lead to lower knee joint compressive forces during walking.

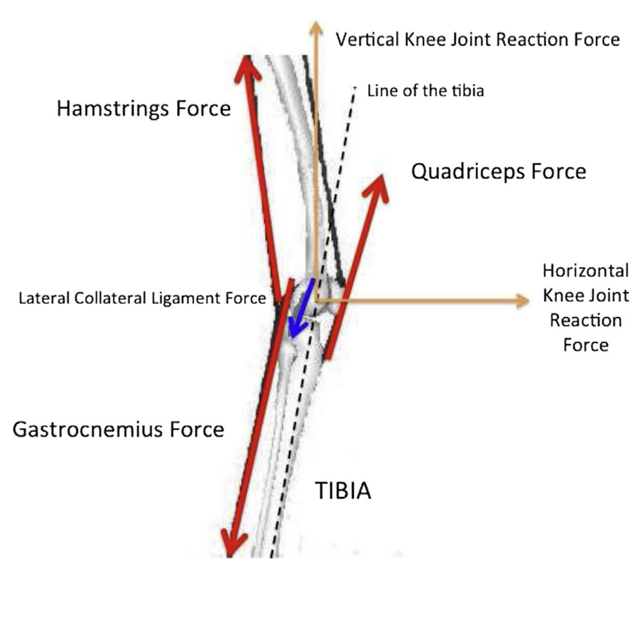

**Table 1**
Baseline values and changes in outcomes in groups and mean differences between groups among the participants who adhered to the protocol

| Variable | Control group ($n = 15$) | | Training group ($n = 15$) | | *Group mean difference | p |
|---|---|---|---|---|---|---|
| | Baseline | Change | Baseline | Change | | |
| Self-selected walking speed (m/s) | 1.52 ± 0.61 | -0.04 (-0.10 to 0.01) | 1.43 ± 0.21 | 0.04 (-0.01 to 0.09) | -0.08 (-0.15 to -0.01) | 0.018 |
| 1st peak knee compressive fore; (N/kg) | 40.7 ± 5.4 | -1.60 (-4.35 to 1.15) | 34.5 ± 6.7 | 0.86 (-1.91 to 3.64) | -2.47 (-6.47 to 1.53) | 0.22 |
| 1st Quadriceps peak force (N/kg) | 21.7 ± 5.9 | -0.54 (-2.83 to 1.75) | 17.3 ± 5.4 | 1.96 (-0.26 to 4.18) | -2.50 (-5.71 to 0.70) | 0.12 |
| Quadriceps Isometric strength (Nm/kg) | 1.52 ± 0.61 | -0.11 (-0.41 to 0.19) | 1.32 ± 0.43 | 0.26 (-0.03 to 0.54) | -0.37 (-0.73 to -0.002) | 0.049 |
| WOMAC pain (0-100 score, higher score is worse) | 25.0 ± 18.2 | 3.20 (-2.3 to 8.6) | 19.7 ± 17.2 | -5.30 (-11.6 to -0.1) | 9.0 (1.7 to 16.3) | 0.018 |
| WOMAC Function (0-100 score, higher score is worse) | 29.9 ± 13.3 | -2.1 (-8.6 to 4.4) | 21.9 ± 14 | -14.0 (-20.9 to -7.0) | 11.9 (2.6 to 21.1) | 0.014 |
| WOMAC stiffness (0-100 score, higher score is worse) | 31.9 ± 24.9 | -1.8 (-10.5 to 6.9) | 24.7 ± 20.7 | -10.4 (-19.4 to -1.3) | 8.55 (-3.1 to 20.2) | 0.14 |
| WOMAC total (0-100 score, higher score is worse) | 34.0 ± 14.7 | -0.4 (-7.5 to 6.8) | 27.7 ± 14.6 | -15.9 (-23.4 to -3.4) | 15.5 (5.4 to 25.6) | 0.004 |

Baseline values are mean ± standard deviation. Changes are per protocol mean (95% confidence interval). *Based on ANCOVA, adjusted for age, gender, baseline value, and study center location. P-values indicate whether changes are significantly different between groups. Level of significance p<0.05.

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## INTEGRATIVE ASSESSMENT OF FRONTAL PLANE ALIGNMENT OF THE HIP AND KNEE AMONG SUBJECTS WITH AND WITHOUT KNEE OSTEOARTHRITIS: THE MOST STUDY

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**Purpose /Aims**: Knee alignment is a putative risk factor for medial and lateral knee osteoarthritis (OA). Anatomical variations at the hip have potential to influence knee alignment and thereby increase risk of medial or lateral knee OA. To better understand the relationship between malalignment and knee OA, it is useful to explore whether anatomical variations more proximal in the kinetic chain are associated with the static alignment of the knee and whether these associations differ between the two main methods of assessing static knee alignment.

This study has two aims: 1) compare how variations in pelvic anatomy relate to the mechanical axis, anatomical axis, and also the magnitude of difference between axes, and 2) explore whether any differences between axes relate to prevalence of compartment-specific knee OA.

**Methods**: This cross-sectional study uses publicly released data from the Multicenter Osteoarthritis Study (MOST), an observational cohort study of incident and progressive knee OA in men and women ages 50-79 years at baseline.

We report on 1,328 hips/knees from 664 subjects: 160 subjects with lateral OA (101 unilateral/ 59 bilateral), 168 subjects with medial OA (76 unilateral / 92 bilateral), and 336 control subjects. All participants with LOA at the baseline MOST visit were included. An equal number of participants with MOA, and twice the number of controls were then randomly selected. Case knees were identified as having Kellgren/ Lawrence (K/L) ≥ 2 with joint space narrowing (JSN) score ≥ 1 (0-3 OARSI atlas scale) in the specified compartment with no JSN in the adjoining compartment.

Measurements of hip anatomy and knee alignment were taken from full-limb standing radiographs using custom OsiriX software by an author (AB) blinded to knee OA status, and unreadable radiographs ($N = 8$) were discarded prior to unblinding. Knee measurements included the hip-knee-ankle angle (HKA-mechanical axis), femoral-shaft tibial-shaft angle (FSTS-anatomical axis), and femoral mechanical-anatomical angle (FMA). The FMA represents the magnitude of difference between the anatomical and mechanical axes (FSTS – HKA), with neutral alignment defined as 0°, valgus >0° and varus <0° (Fig 1a). Hip measurements included femoral neck-shaft angle (NSA), femoral neck length (FNL), and femoral offset (FO).

Hip variables were compared to knee alignment using Pearson bivariate correlation analyses. Multiple logistic regression with generalized estimating equations (GEE), to account for potentially correlated observations for knees and hips from the same person, was used to evaluate the relationship between knee alignment and prevalence of medial or lateral knee OA. All analyses were adjusted for age, gender, and body mass index (BMI).

**Results**: The FMA angle correlated strongly with FO (r = 0.82, p<0.001) and NSA (r = -0.71, p<0.001), and moderately with FNL (r = 0.53, p<0.001). As NSA increased, or as FO decreased or FNL shortened, FMA decreased. FMA had a significant inverse relationship to HKA (r = -0.13, p<0.001), and a non-significant direct relationship to FSTS (r = 0.06, $p$ = 0.053). Femoral NSA, FO, and FNL all had statistically significant relationships (p<0.001) with HKA, but the strength of these relationships was weak: FO (r = -0.23), NSA (r = 0.19), FNL (r = -0.15). None of the hip variables had a significant relationship with FSTS: FO (r = -0.05, $p$ = 0.067), NSA (r = 0.04, $p$ = 0.159), FNL (r = -0.03, $p$ = 0.225).

The mean ± standard deviation for FMA was 5.55° ± 0.77 for those with lateral OA, 5.76° ± 0.79 for medial OA, and 5.80° ± 0.74 for controls. Regression analyses showed FMA is associated with an increased prevalence of lateral OA (OR 1.61, 95% CI 1.27 to 2.05) but not medial OA (OR 0.98, 95% CI 0.77 to 1.24) (Table I). When HKA is controlled for, FMA

**Table I**
Knee alignment and prevalence of knee OA

| | Compared to controls: | |
|---|---|---|
| | Medial OA (or (95% CI)) | Lateral OA (or (95% CI)) |
| HKA | 1.45 (1.35 to 1.57) | 1.68 (1.54 to 1.83) |
| FSTS | 1.47 (1.37 to 1.59) | 1.59 (1.47 to 1.72) |
| FMA | 0.98 (0.77 to 1.24) | 1.61 (1.27 to 2.05) |
| FMA (controlling for FSTS) | 1.19 (0.91 to 1.55) | 2.23 (1.66 to 3.00) |
| FMA (controlling for HKA) | 0.81 (0.62 to 1.05) | 1.34 (1.00 to 1.81) |

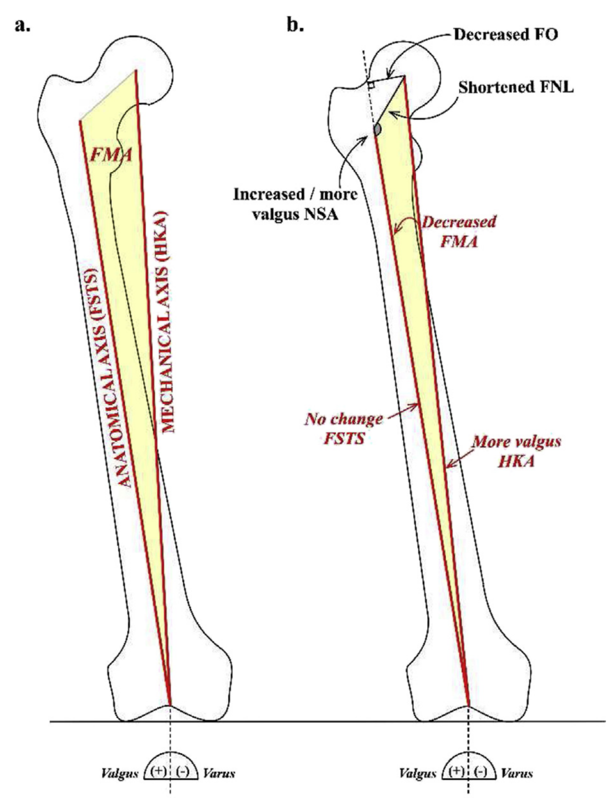


Figure 1. The relationship between hip geometry and knee alignment.